Dipartimento di
Fisica Nucleare e Teorica

Incontri di Fisica delle Alte Energie
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INFN
Istituto Nazionale
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Sezione di Pavia

Single Top At Hadron Colliders

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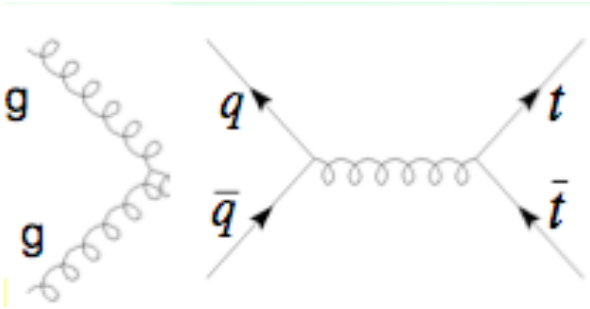
Overview

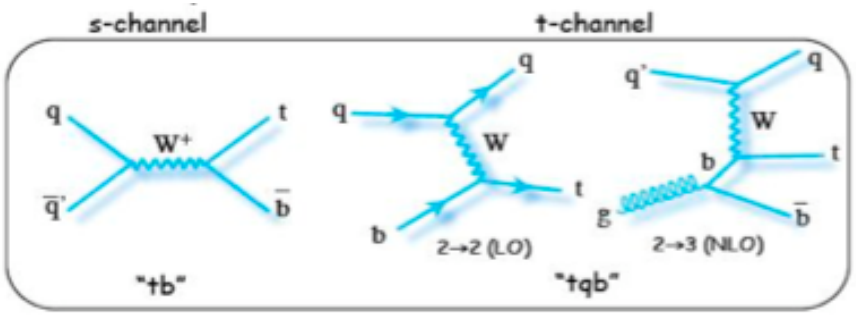
- Searches for single top at the TeVatron
  - Current status
  - Beyond 1 fb expectations
- Single Top at LHC (ATLAS)
  - Analysis strategies
  - Current activities
  - Outlook for 100pb and full statistics
- A couple of phenomenology remarks in single top physics
- Conclusions

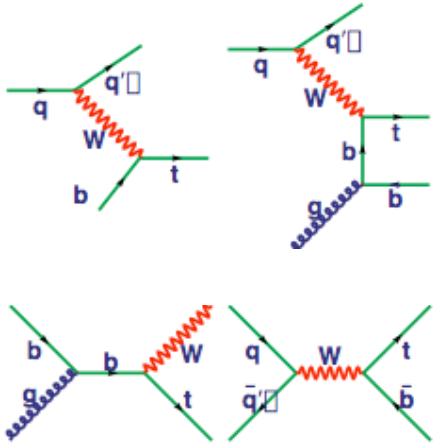
Top production modes

Strong Interactions:tt pair
Dominant mode: $\sigma_{NLO+NLL} = 6.7\ ^{+0.7}_{-0.9}$ pb (TeVatron))
Signature understood (top discovery 1995)



Weak Interactions: single top
Larger background, smaller cross section
Not yet observed at the TeVatron, observable at LHC





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Why Single Top ?

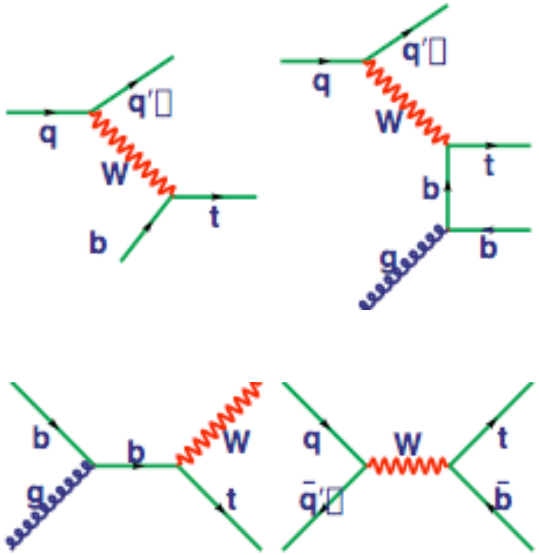
Motivations

- Properties of the Wtb vertex :
  - Determination of $\sigma(pp \rightarrow tX)$, $\Gamma(t \rightarrow Wb)$
  - Direct determination of $|V_{tb}|$
  - Top polarization
- Precision measurements ➔ probe to new physics
  - Anomalous couplings
  - FCNC

  } t-channel,Wt
  - Extra gauge-bosons W′ (GUT, KK)
  - Extra Higgs boson (2HDM)

  } s-channel
- Single-top is one of the main background to …

  … Higgs physics…



M(top) = 175 GeV/c^2		s-channel	t-channel	Associated tW	Combined (s+t)
TeVatron σ_{NLO}		0.88 ± 0.11 pb	1.98 ± 0.25 pb	0.1 pb	
LHC σ_{NLO}		10.6 ± 1.1 pb	247 ± 25 pb	62 $^{+17}_{-4}$ pb	
Run I 95% CL	CDF	<18 pb	< 13 pb	NA	< 14 pb
	D0	< 17 pb	< 22 pb	NA	

σ_{t+s} = 2.9 pb for m(top) = 175 GeV/c^2

B.W. Harris et al.:Phys.Rev.D66,054024 T.Tait: Phys.Rev.D61,034001
Z.Sullivan Phys.Rev.D70:114012 A.Belyaev,E.Boos: Phys.Rev.D63,034012

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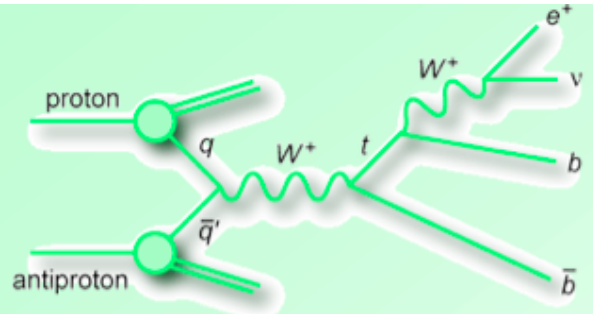
Single Top at the TeVatron

Signatures and Backgrounds

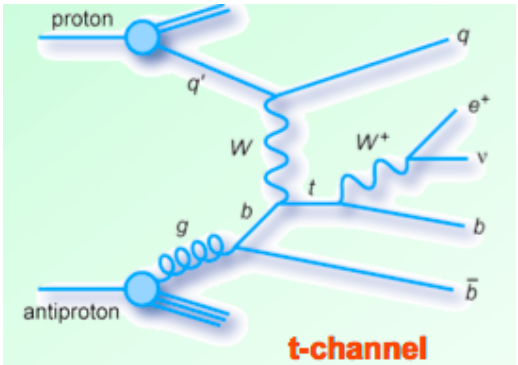


s-channel

W/Z + jets production
Top pair production
Multijet events

$\bar{b}$ quark produced WITH the top
b quark from the top decay
lepton + Missing E_T

1/10



t-channel

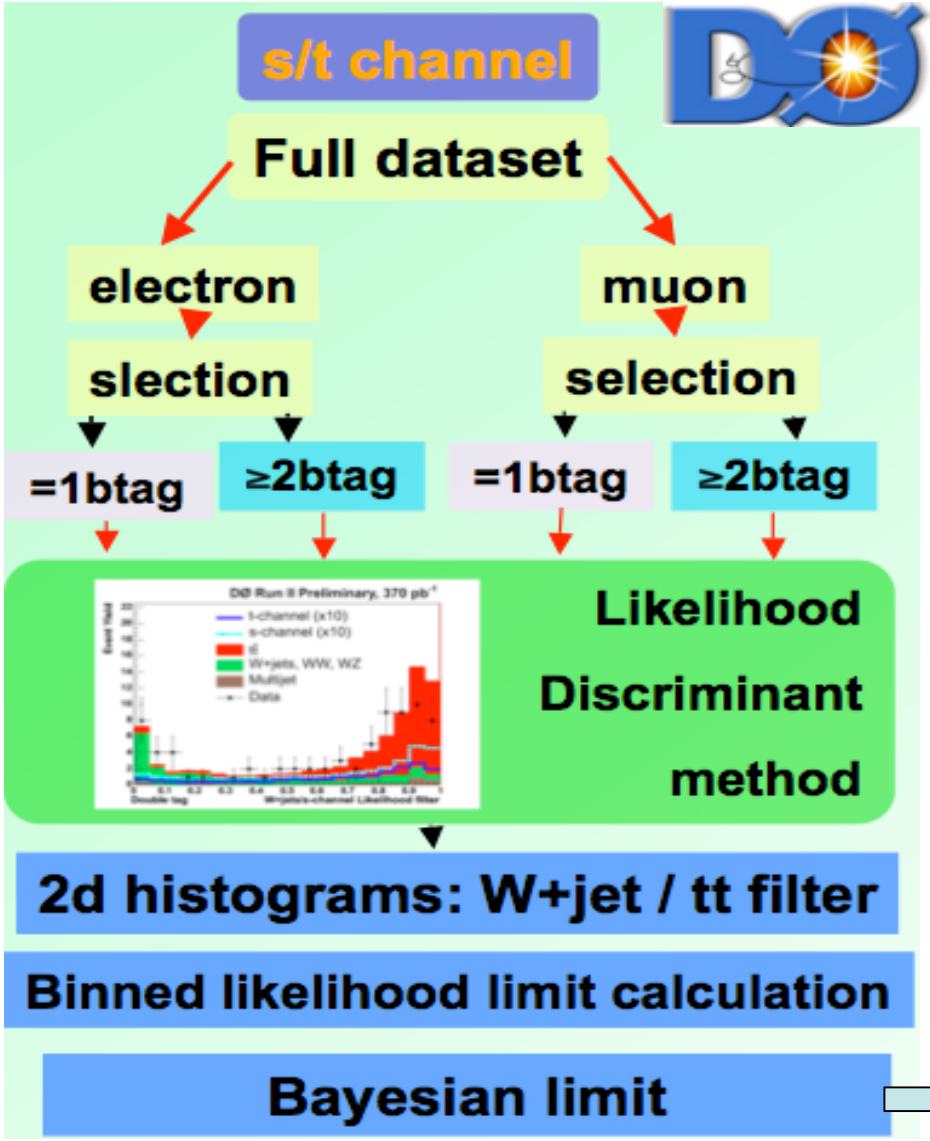
b quark from the top decay
lepton + Missing E_T
extra light quark
at NLO an additional $\bar{b}$ is radiated

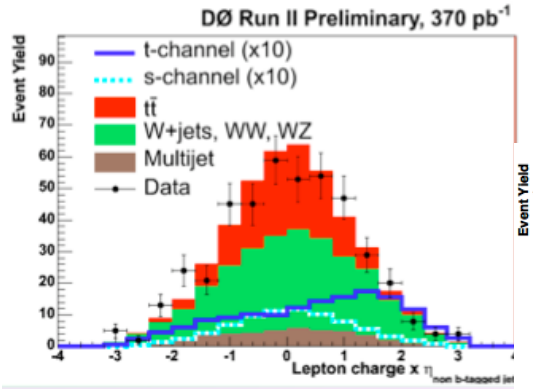
Analysis strategies

CDF- separate channels search (2D NN)
and combined channels search (1D NN and likelihood function compared to 2 hypothesis)

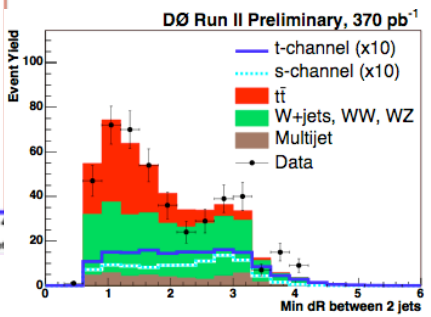
D0 - separate channels search (likelihood discriminant method)

TeVatron Current Results (I)



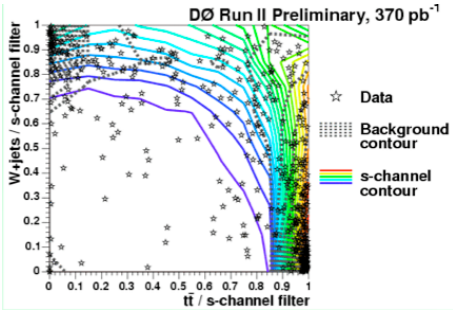


370 pb^{-1}



Study of variables having discriminating power against W + jets/ttbar (Qηfor example) ;
Design of several likelihood discriminants for S/B separation;

Combination of likelihoods in 2D histos;
Extraction of limit



95% C.L. Upper Limit
t-channel σ < 4.4 pb
s-channel σ < 5.0 pb

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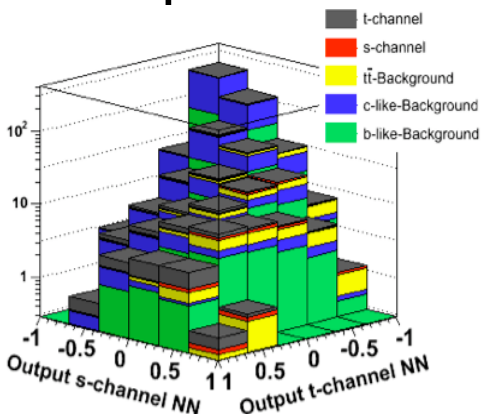
TeVatron current results (II)

Separate channels search

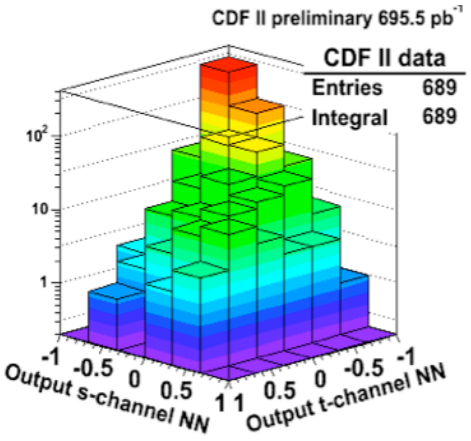
CDF uses *2 networks trained for t- and s-channel* ⇒ *the creation of the templates for signal and background processes is done in 2dim for both network outputs simultaneously!*

695 pb^{-1}

Expected

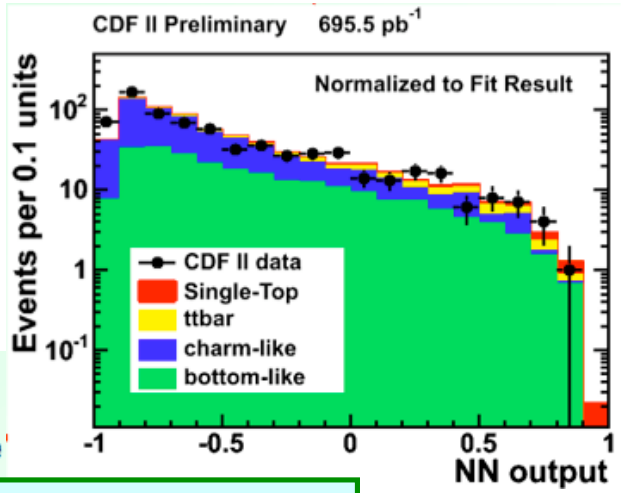


Data



Likelihood fit is applied to the output of the 2D NN:

t-channel: σ < 3.1 pb @ 95% C.L.
s-channel: σ < 3.2 pb @ 95% C.L.



Combined Channels

For the combined search, CDF uses *1 network* trained with t-channel and s-channel events as signal to search for single top assuming the ratio between the two processes to be as predicted by SM

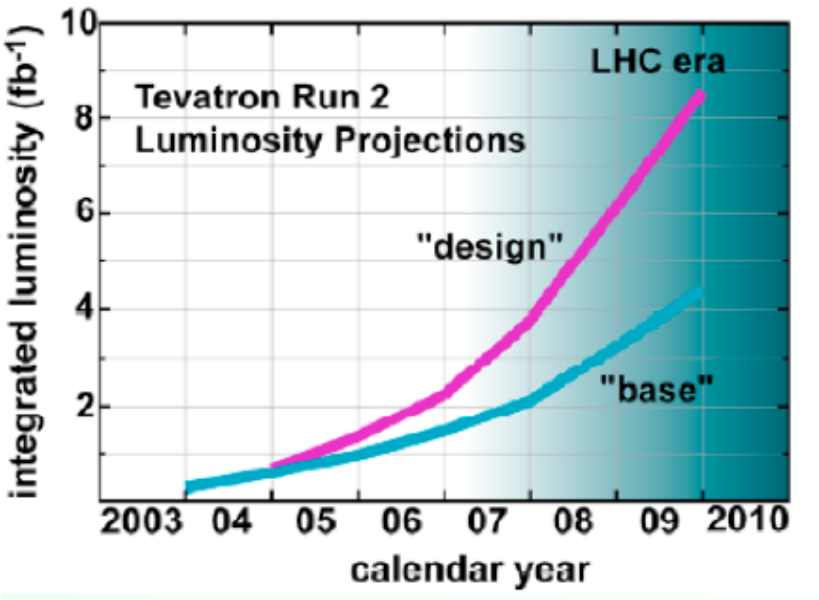
(s+t) Upper Limit
σ < 3.4 pb @ 95% C.L.

TeVatron outlook

Assume no improvement in analysis technique, methods, and resolution:

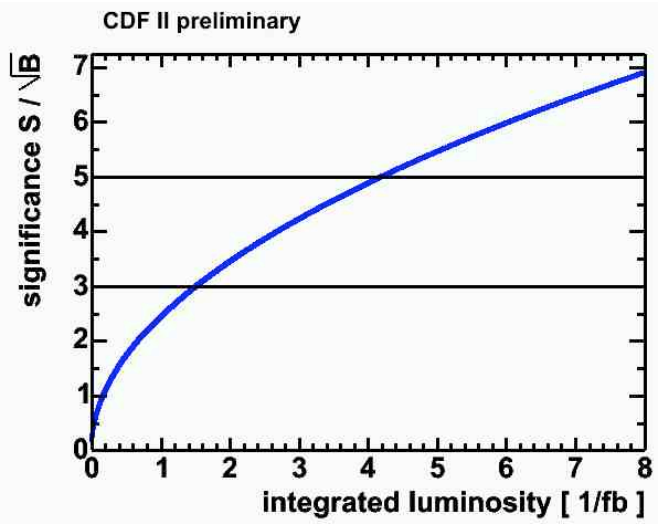
- it will take 1.5 fb^{-1} of data to have an evidence for a single top production for one experiment!

Both experiments have more than 1 fb^{-1} on tape!



Expectations @ Run II (2 fb^{-1})

- **5σ-discovery ? X-sections known at ~ 25%**



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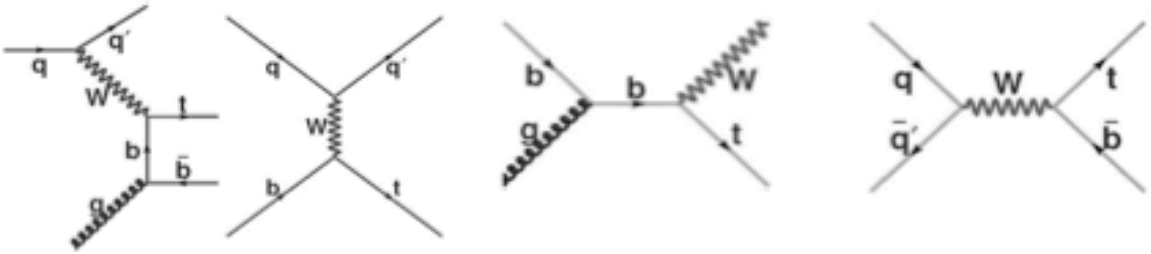
Single Top at LHC

- **All 3 contributing mechanisms in SM:**

W-g (t-channel) W+t W* (s-channel)



- **Computation at NLO available for W* and W-g :**
  - Increase of σ(W*) by ~30 %
  - Affect p_T(jet) distribution, H_T etc…

Decay modes:

- W* : W* → t bbar → ($l^+\nu$b) bbar
- Wg: q'g → t q bbar → ($l^+\nu$b) q bbar
- W+t: bg → t W → ($l^+\nu$b) qq'

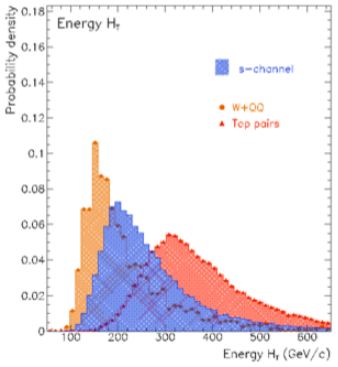
1 leptons + MET
+ ≥ 2 jets
+ 1(2) b-tags

Channel	σ x BR(pb)
W-g	54.2
W+t	17.8
W*	2.2
ttbar	246
Wbb	66.7
W+jets	3,850

Our main backgrounds :
~ 1/1000 ttbar
~ 3/1000 Wbb
~ 0.5/1000 W+njets

Common selection for all 3 single-top samples :

- 1 High pT Lepton + mET
→ reduce non-W events
- At least two high-p_T jets
→ reduce W+jets events



- Single-top ~22-26%
- ttbar ~ 38%
- WQQ ~ 1.5% , W+njets < 1/1000

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ATLAS analysis strategies

In the late '90 several studies were conducted to produce a physics TDR. Current studies are meant to devise analysis strategies for first data (100 pb^{-1}) and the full statistics, using the latest software tools.

Description of cuts	Cumulative Selection Efficiency (%)			
	W-g fusion	$t\bar{t}$	$Wb\bar{b}$	*Wjj*
Pre-selection cuts	20.0	44.4	2.49	0.667
Njets = 2; p_T>30GeV	13.2	0.95	0.99	0.37
Forward jet; p_T>50, $\|\eta\|$>2.5	4.3	0.046	0.072	0.06
m_{tot}>300 GeV	3.58	0.025	0.043	0.048
H_T > 200 GeV	2.08	0.019	0.036	0.027
150 < m_t < 200 veto	1.64	0.01	0.0052	0.0066
Events/30 fb^{-1}	26 800 ± 1000	720 ± 160	104 ± 60	7900 ± 1600

Description of cuts	Cumulative Selection Efficiency (%)					
	*W**	*W-g* fusion	*Wt*	$t\bar{t}$	$Wb\bar{b}$	*Wjj*
Pre-selection cuts	27.0	20.0	25.5	44.4	2.49	0.667
njets = 2; p_T > 30 GeV	15.7	6.8	3.79	0.93	1.35	0.201
nb-jet = 2; p_T > 75 GeV	2.10	0.05	0.018	0.023	0.038	0.0005
scalar sum of p_T >175 GeV	1.92	0.036	0.016	0.021	0.030	0.0004
m_{tot}>200GeV	1.92	0.036	0.014	0.021	0.025	0.0003
150<m_{lvb}<200 GeV	1.67	0.031	0.008	0.017	0.016	0.0002
Events/30 fb^{-1}	1106 ± 40	510 ± 148	42 ± 21	1290 ± 228	328 ± 61	226 ± 113

Description of cuts	Cumulative Selection Efficiency (%)		
	Wt	$t\bar{t}$	$Wb\bar{b}$
Pre-selection cuts	25.5	44.4	2.49
njets = 3; p_T > 50 GeV	3.41	4.40	0.05
nb-jet = 1	3.32	3.24	0.037
m_{tot} < 300 GeV	1.43	0.71	0.008
65 < m_{jj} < 95 GeV	1.27	0.41	0.003
Events/30 fb^{-1}	6828 ± 269	30408 ± 742	58 ± 19

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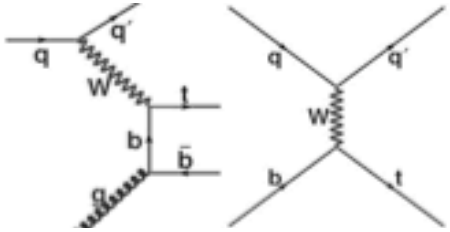
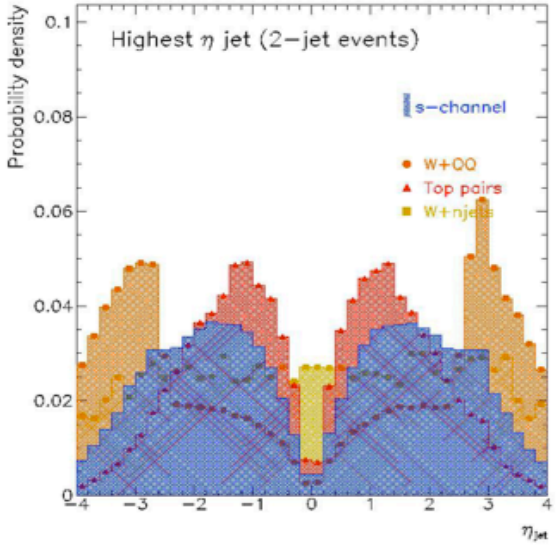
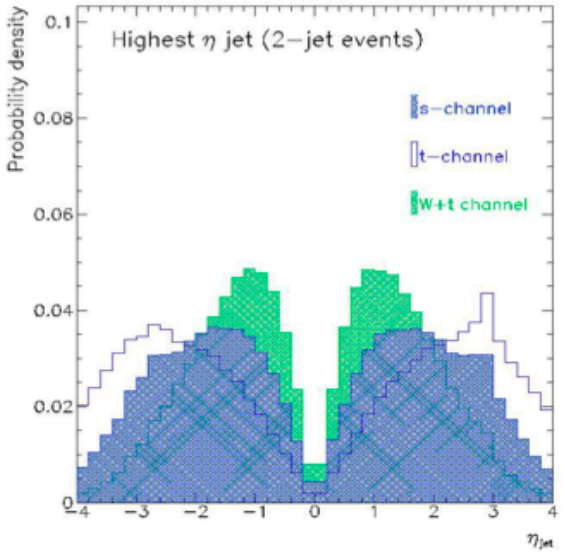
Wg channel







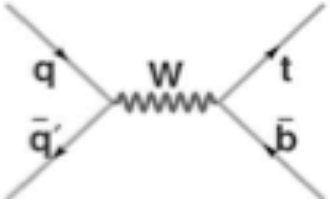
Selection criteria

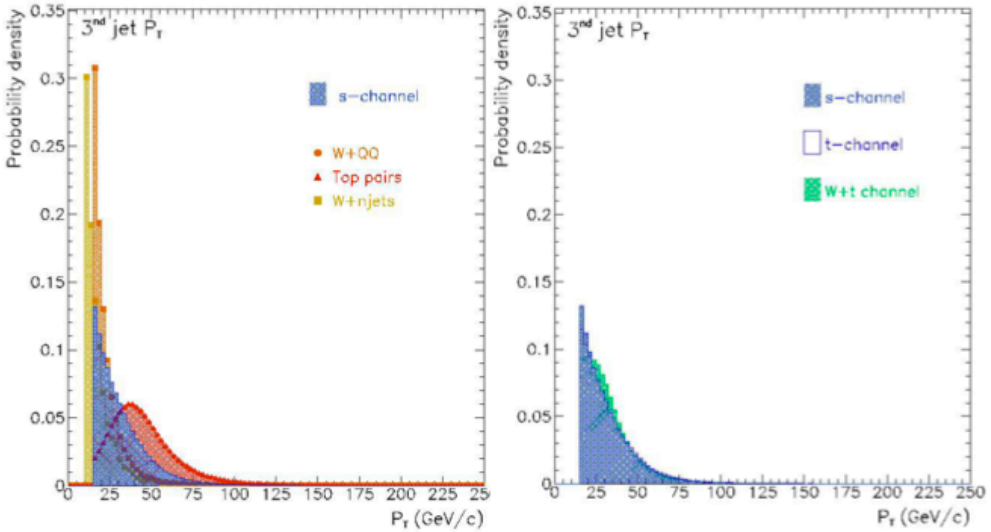
- Number of jets : N(jet) = 2
- Presence of a high-p_T b-tagged jets (p_T>40GeV/c)
  Wg evts have 1 b-jet escaping the acceptance
  → requires **only** 1 b-tagged jet
- Presence of a high-p_T forward jet
  → 1 jet with |η|>2.5 and $p_T \geq$ 50GeV/c
- Reconstruct M_{lvb} within ±25 GeV/c^2
- Window in H_T

	W*	Wg	W+t	tt	WQQ	W+jets
Pre-Selection (%)	26.2	23.7	22.4	38.3	1.46	0.05
Selection ε(%)	0.22	0.44	0.023	0.007	0.006	0.0013
N^{event}(30 fb^{-1}) ± MC stat.	150 ± 6	7,080 ± 160	125 ± 13	500 ± 150	130 ±40	1,500 ± 750

- N(jet) = 2 → reduces tt by ~6 vs Wg
- 1 high-p_T fwd jet → reduce tt (by ~5), Wt(~10), Wjj(~2)
- Great uncertainty on WQQ / W+jets backgrounds

s-channel





Selection criteria

- Number of jets : N(jet) = 2
- Presence of two high p_T jets
- Presence of two central, high-p_T b-tagged jets
  → Wq usually have 1 b-jet escaping the acceptance
- Reconstruct M_{lvb} within $m_{top} \pm 25$ GeV/c^2
- Window in H_T

	W*	Wg	W+t	tt	WQQ	W+jets
Pre-Selection ε(%)	26.2	23.7	22.4	38.3	1.46	0.05
Selection ε(%)	1.73	0.105	0.002	0.035	0.059	0.0001
N^{event}(30 fb^{-1}) ± MC stat.	1,141 ± 7	1,680 ± 48	10 ± 3	2,580 ± 150	1,148 ± 38	170 ± 85

- N(jet) = 2 → reduces tt by a factor ~ 20 vs W*
- 2 high-p_T b-jets → reduces WQQ by ~2 and Wg by ~8
- M_{lvb} and H_T → reduce non-top by ~2

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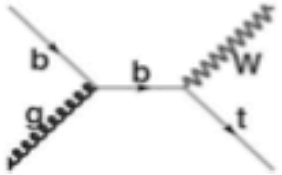
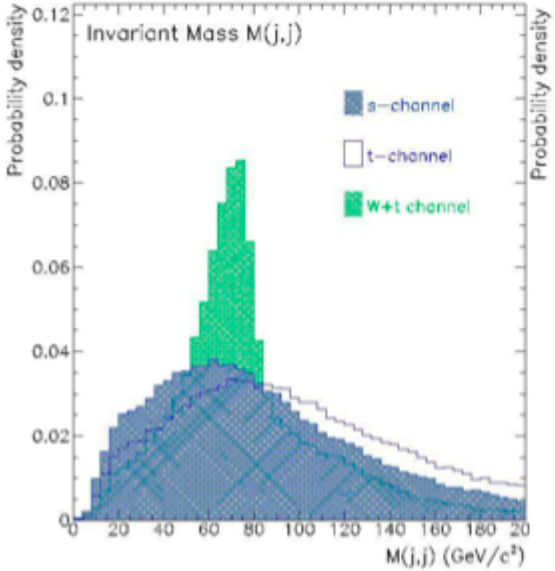
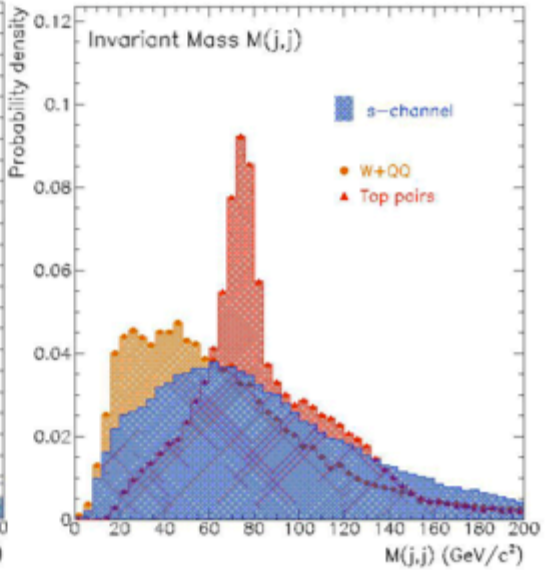
Wt channel



Selection of a specific topology

- Number of high-p_T jets Njet) = 3
- Presence of a high-p_T b-tagged jets
  → Only **one** b-jet in W+t events
- Presence of a W-boson mass peak
  → requires 60 < M(j,j) < 90 GeV/c^2





- Reconstruct M_{lvb} within ±25 GeV/c^2
- Window in H_T or Invariant Mass

	W*	Wg	W+t	tt	WQQ	W+jets
Pre-Selection ε(%)	26.2	23.7	22.4	38.3	1.46	0.05
Selection ε(%)	0.16	0.25	0.88	0.35	0.004	0.0003
N^{event}(30 fb^{-1}) ± MC stat.	105 ± 5	4,050 ± 80	4,720 ± 80	26,300 ± 400	90 ± 20	xxx ± 85

- N(jet) = 3 → reduces Wjj & WQQ ~3.5 wrt W+t
- M(jj) ~ M_W → reduces WQQ/jets by ~3 wrt W+t

→ Good knowledge of tt background is mandatory

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Top Physics for Commissioning

- Many detector-level checks (tracking, calorimetry etc)
- Try to see large cross section known physics signals
- But to ultimately get to interesting physics, also need to calibrate many higher level reconstruction concepts such as jet energy scales, b-tagging and missing energy

Algorithms benefiting from early data for calibration include

- B-tagging
  - Identify jets originating from b quarks from their topology
  - Exploit relatively long lifetime of B decays → displaces vertex
- Jet energy scale calibration
  - Relate energy of reconstructed jet to energy of parton
  - Detector and physics calibration (some fraction of parton energy is undetectable to due production of neutrinos, neutral hadrons etc…).
  - Dependent of flavor of initial quark → need to measure separately for b jets

Current Activities

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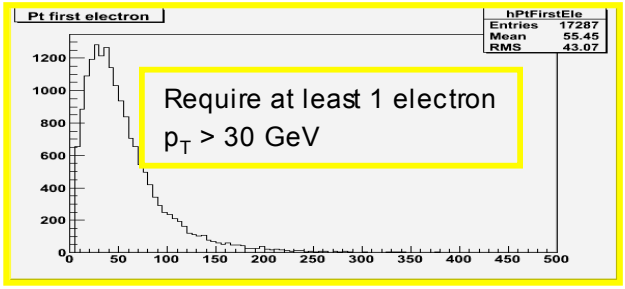
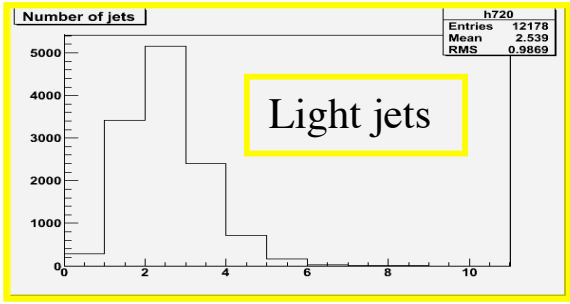
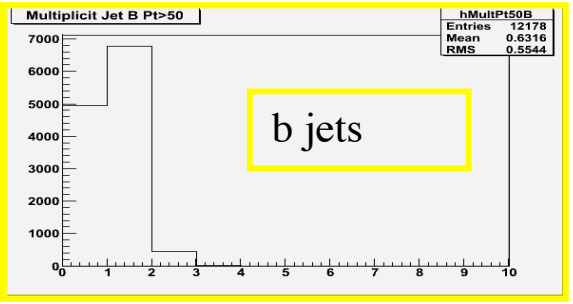
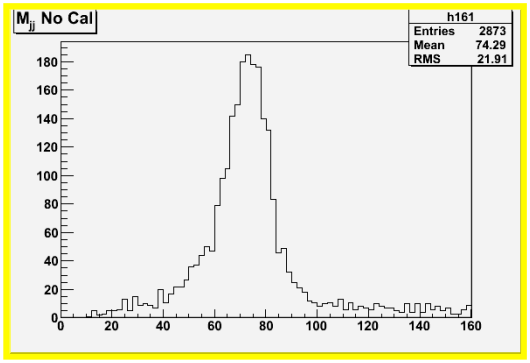
Current Activities

Fast Simulation vs Full Simulation

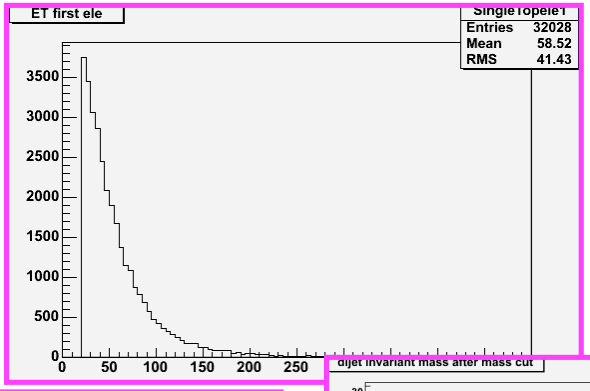


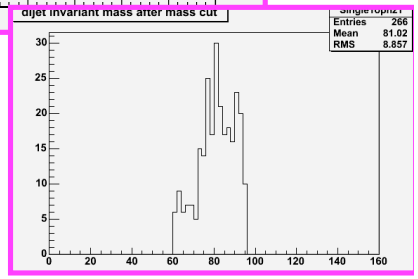






All evts	40000
1 lepton	12178
1 b jets pt 50	6788
2 light jet pt 30	2873 (7.1%)



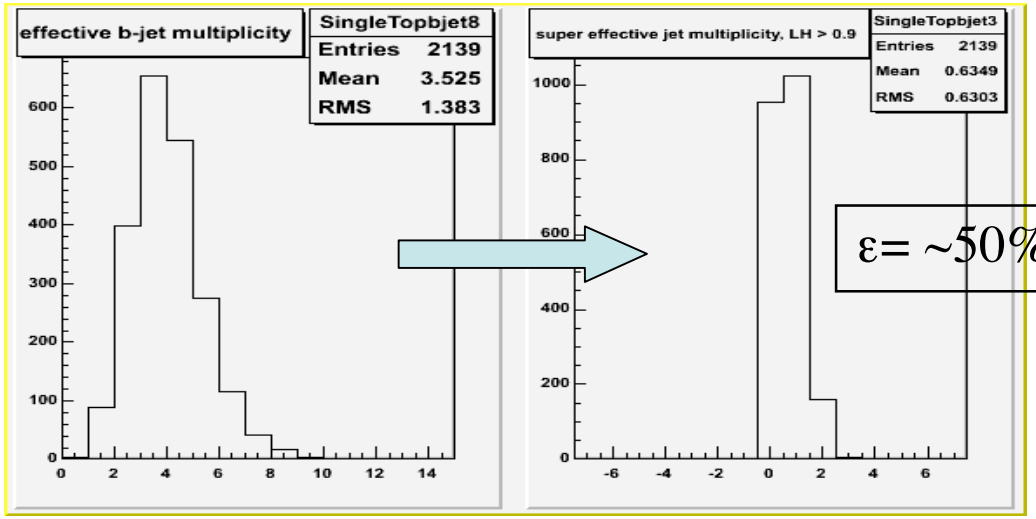


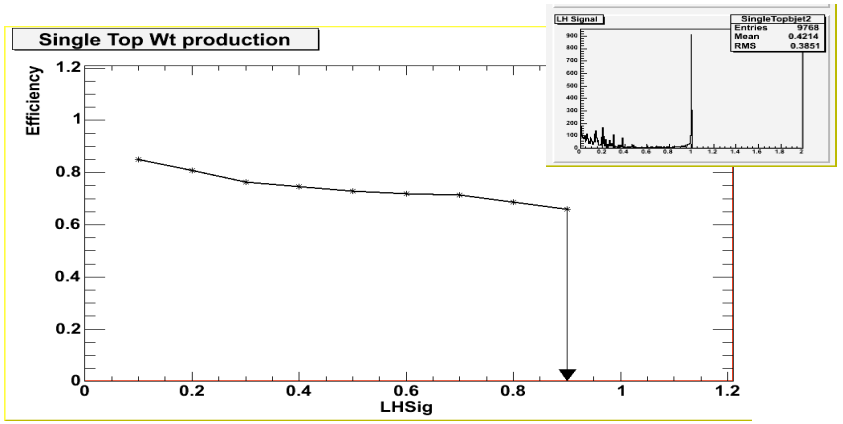
32028 evts with 1 one P_T ele (XRatio > 0.6)
28582 evts with MET > 20 GeV
12175 evts with 1 and only 1 b-jet (Lhsig > 0.9, E_T > 50, η < 2.5)
1566 evts with 2 jets (3 total) E_T > 30, η < 2.5

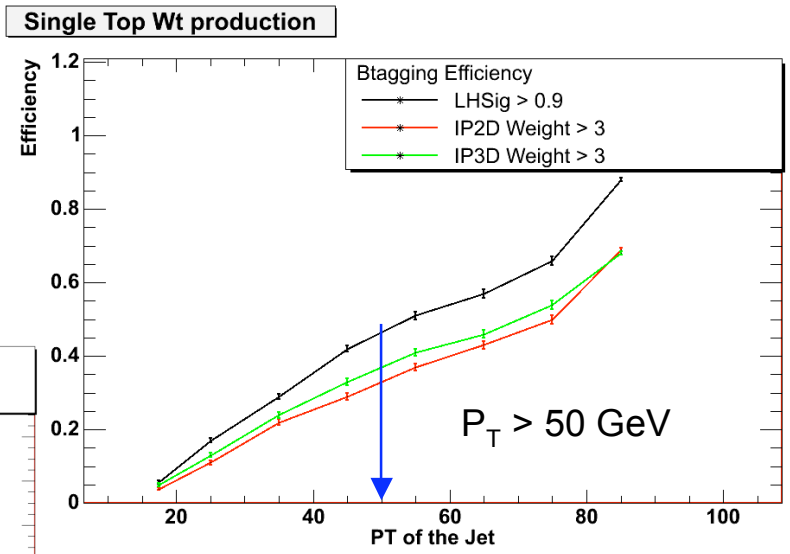
2.4% final acceptance (3% TDR)

Current Activities (II)

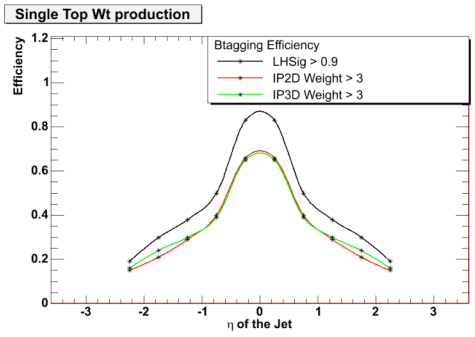
b-tagging efficiencies







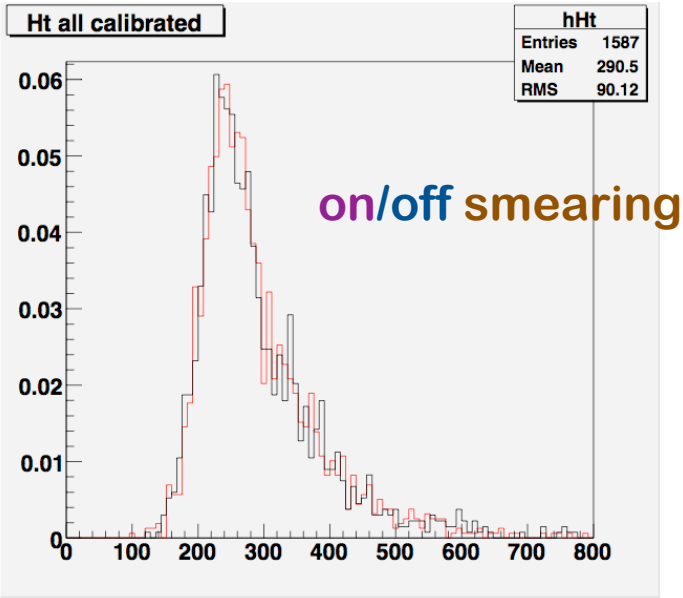
- Several algorithms in testing phase
- LHSig shown
- Efficiencies as function of cut and P_T and η



Current Activities (III)

Systematic uncertainty

Calorimeter resolution



on/off smearing

- **Parton Distribution Function (PDF) :**
  - CTEQ5M1 vs CTEQ6M

hep-ph/0408049

Channel	σ(pb)	Uncertainties		
		PDF	μ-scale (μ/2-2 μ)	Δm_{top} (4.3GeV)
W-g	246.6 ± 8.7	4%	3%	1%
W+t	60 ± ??	10%	?	1%
W*	10.6 ± 0.7	4%	2%	3%

- **Theoretical uncertainties:**
  - Quark-gluon luminosity --choice of the (b) PDF
  - Renormalization scale μ
  - Δm_{top} (175 to 178 GeV → σ(W*) down by 6%)

Phenomenology Work

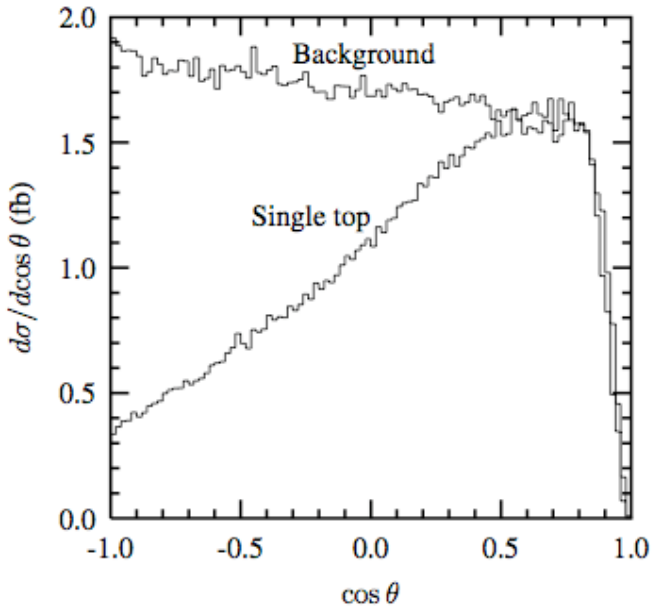
Angular correlations in single top and Wjj production (NLO)

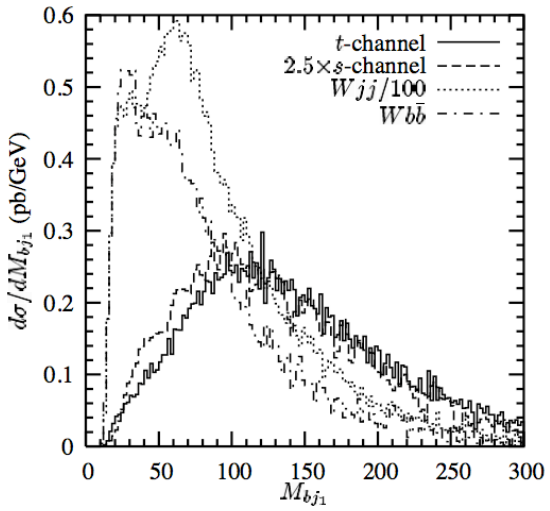
Phys.Rev.D72:094034,2005

1. Angular correlations in single-top-quark production are a composite of spin correlations, and kinematic correlations.

   They can be reliably predicted for both single top production and Wjj. Using fully correlated angular distribution a set of cuts is devised

2. Huge gains are possible if cuts are made on the reliably predicted angular distributions.
   - $S/B \sim 3 \times S_0/B_0$, $S/\sqrt{B} > 1.25 \times S_0/\sqrt{B_0}$ — refine w/ detector sim.
   - Spin-dependent LO ME are fine, t-channel needs matched ME





1. $\cos\theta^t_{eb} < \cos\theta^t_{ej_1}$.
2. $\cos\theta^t_{bj_1} < \cos\theta^t_{ej_1}$.
3. $\cos\theta^t_{bj_1} < 0.6$–$0.8$.
4. $\cos\theta^t_{ej_1} > 0$–0.4 or $\cos\theta^t_{eb} > -0.8$.
5. $M_{bj_1} > 80$–120 GeV

$S/\sqrt{B} \approx S_0/\sqrt{B_0}$, $S/B \approx 1.5 \times S_0/B_0$

Result: $S/\sqrt{B} \approx 1.25 \times S_0/\sqrt{B_0}$, $S/B \approx 3 \times S_0/B_0$

Phenomenology Work

Using charge asymmetry to measure single top production

hep-ph/0503110

- LHC is a gluon collider – tt goes up, tbq goes up, W+jets only somewhat, tb very little
- ttbar really will be the dominant background
- It has been that showed jet veto can reduce tt enough to study single top in single tag channel (hep-ph/9807340)
  - But jet veto was not enough to study single top in double b-tagged sample
- Charge asymmetries eliminate tt more effectively than jet vetos, allowing both single-tag and double-tag single top samples to be studied
  - s-channel and t-channel both have cross-sections with charge asymmetries $A_C \sim 0.25$
  - Wt channel not affected (b and bbar PDF are assumed to che charged-symmetric)
- W+jets remains the main source of background.

Channel	N_{total}	Δ	$\sqrt{N_{total}}$
tb	4,550	990	67
tbq	116,000	30,900	340
$Wb\bar{b}$	21,900	4,820	150
Wjj	236,000	18,000	490
$t\bar{t}$	958,000	-479	980
Total	1.34M	54,200	1,200

TABLE III: Numbers of events with 1 b-tag for 10 fb^{-1}. $t\bar{t}$ is assumed to have a -0.05% charge asymmetry.

$$A_C = \frac{N_+ - N_-}{N_+ + N_-}$$

Δ: $N_+ - N_-$

Channel	N_{total}	Δ	$\sqrt{N_{total}}$
tb	1,790	330	42
tbq	15,100	4,030	120
$Wb\bar{b}$	8,800	1,800	94
Wjj	1,550	30	40
$t\bar{t}$	336,000	-167	580
Total	363,000	6,020	600

TABLE IV: Numbers of events with 2 b-tags for 10 fb^{-1}. $t\bar{t}$ is assumed to have a -0.05% charge asymmetry.

Conclusions

- Single Top is still elusive…on its way to be observed at the TeVatron, though.
- Single Top will be an interesting process to study at LHC, both in the beginning (low luminosity phase) and later
- Lots of work is ongoing both at the Tevatron and LHC will surely benefit from the experience.

Simona Rolli - Tufts University

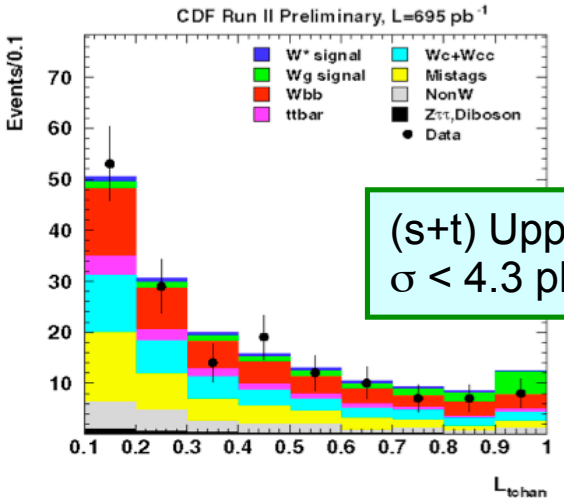
TeVatron current results (III)

Combined Channels likelihood

Using one variable: the t-channel likelihood

Searching for s+t combined signal:

- **Null hypothesis H0: no SM single-top, just SM backgrounds**
- **Test hypothesis H1: SM single-top +SM backgrounds**



695 pb^{-1}

(s+t) Upper Limit
σ < 4.3 pb @ 95% C.L.